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Greenhouse and Open Sun Drying of European Plums (*Prunus domestica* L.)

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Abstract: The present study focused on the determination of suitable drying strategy for rural areas. Therefore, two different drying methods (greenhouse dryer and open sun drying), pretreatment of plums with 1% NaOH solution and halving-pitting of plums were considered. Halved-pitted plums typically dried in 6 to 12 days in greenhouse dryer. Drying time of halved plums under open atmosphere changed between 13 to 22 days. Whole plums decayed considerably before the completion of drying. Water soluble solid content and total titratable acid content of prunes ranged between 64 and 69.8%; 0.23% malic acid and 0.87% malic acid, respectively. Halving-pitting plums and the use of solar dryers (greenhouse dryer in this research) are recommended for successful prune production in rural areas.

Key words: Prune, solar drying, chemical pretreatment, Turkey

INTRODUCTION

Drying as a preservation method of agricultural materials has been practiced by humankind since ancient times. Drying technique extends the shelf-life of the dried products by reducing the microbial degradation and minimizes the costs of packing and transporting due to the reduction of weight and volume of fresh agricultural materials[1]. Some of dried agricultural products such as raisin, prune and dried fig can be thought as new products different from their original fresh materials because of their own tastes and flavors. Dried plums known as prunes are normally produced from specific plum cultivars suitable for drying based on high solid content associated with high level of sugar content[2,3]. Plums are commonly dried by hot air dying. The worldwide production of prune is above 275 000 metric tons. The main prune producers are USA, France, Italy, Argentina, Chili and Turkey[4].

Fresh plums and prunes contain carbohydrates, low fat and low calorie. They are also rich in vitamins A and C, calcium, magnesium, iron, potassium and fiber[5,6]. In addition to prune production, fresh plums are used to produce jams, juice and syrups[6].

Open sun drying is the common drying method of agricultural materials used in Turkey[7]. However, this method results in long drying times and quality loses since the drying materials are directly exposed to weather conditions and environmental contamination. On the other hand, artificial hot air dryers have high investment cost and high energy expenses. Solar drying can be a viable drying method minimizing energy cost and microbial spoilage while speeding up moisture loss. For this purpose, while special solar dryers such solar greenhouse dryers can be used, greenhouses normally utilized for plant production can be rearranged for drying when they are not used for plant production[8-10].

Plum drying is a slow process since the plum skin is covered by a waxy layer impermeable to moisture. To accelerate moisture loss, plums can be dipped into the solutions of various chemicals such as ethyl oleate, NaOH and K_2CO_3[6,11,12]. Chemical pretreatments normally breaks down the waxy cuticular fruit surface and create microscopic cracks which increase moisture permeability.

Even tough plums are widely grown in Tokat Province, prune production by open sun drying is limited by weather condition. This study aimed to determine the suitable drying method for plums in rural areas based on the drying characteristics and quality attributes of three European plum cultivars (Giant, Stanley, President) grown in this region under various drying conditions. They are dried in the greenhouse dryer of Farm Machinery Department, Faculty of Agriculture, Gaziosmanpasa University. Traditional open sun drying is used as control drying method.

MATERIALS AND METHODS

Fresh plums were provided by the Fruit Production Station of Turkish Ministry of Agriculture located in Tokat Province. Some chemical and physical properties of fresh plums were given in Table 1. They reached their

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Table 1: Some physical and chemical properties of fresh plums

Fruit properties	Stanley	Giant	President
WSSC (%)	16.75	14.83	13.50
Initial moisture content (% wb)	84.20	84.21	85.00
TAC (% malic acid)	0.84	0.93	0.90
pH	4.06	3.91	3.87
Single fruit weight (g)	23.70	68.50	49.80
Fruit length (mm)	42.90	59.70	52.10
Fruit width (mm)	32.20	46.82	42.10
Single fruit volume (mm)	23.30	63.30	45.41
Fruit skin thickness (mm)	0.241	0.161	0.240
Color	Purple-Black	Dark Red-Purple	Claret Red

harvest maturity at different times (August 31 for Giant, September 11 for Stanley and September 15 for President). Tokat is located in the Central Black Sea Region of Turkey. Its latitude, longitude and elevation (m) are 40.18, 36.54 and 608, respectively. The greenhouse dryer was a tunnel plastic dryer whose width, length and heights were 6, 18 and 3 m, respectively. The greenhouse drier had a concrete floor and its long side oriented in west-east direction. There was entrance door in east side and a 0.55 kW fan with 23000 $m^3 h^{-1}$ airflow rate in west side. However, fan was not operated during drying trials because total amount of samples were not much.

Plums were carried in plastic bags from the production station to the greenhouse dryer and the drying trials were immediately initiated after selecting plums in similar size for each cultivars. The experimental layout of this study was as follows:

Physical treatment: Whole plums (W) versus plums (H) halved and pitted.

Chemical treatment: Untreated plums (U) versus plums (T) dipped in 1% NaOH solution for 15 sec as recommended[12,13].

Drying method: Greenhouse drying (G) and open sun drying (O).

Around 200 g plum samples for each treatment combination were placed in net-bags. Dipped samples (T) were immediately rinsed with water and the samples were left on paper towels for a while to remove freely-flowing water on the samples. The samples were initially weighed and placed on drying trays whose bottom was covered by wire mesh in both greenhouse dryer and outdoor for open sun drying. Thin layer of the samples was ensured to let drying air freely flow through samples. Drying process was continued until the moisture content of plums falls down to 25-30%[14]. The moisture content of fresh plums was determined according to the vacuum oven method[15]. An electronic caliper with 0.01 mm sensitivity were used to determine plum sizes. The skin thickness of plums was determined with a SOMET CSN 251420 μm (0-25/0.01 mm sensitivity). The samples were weighed with an electronic balance with 0.01 g sensitivity at various time points during drying trials to follow the weight changes of the samples.

The temperature and relative humidity of air inside greenhouse dryer were hourly measured and recorded with a combined electronic sensor-recorder. The temperature and relative humidity of outdoor air were provided by a local weather station belonging to the Research Institute of Tokat Rural Affairs 1 km away from the greenhouse dryer. pH, total Titratable Acidity Content (TAC), total Water Soluble Solid Content (WSSC) were determined as described by Turkish Standards[16-18].

RESULTS

Drying of giant plum: Daily average greenhouse air temperature was 27.7±2.2°C while daily average outdoor temperature was 20.3±2.0°C (Fig. 1). It means that greenhouse dryer provided 7°C hotter air on the average. In addition, this increase in air temperature resulted approximately in a reduction of 10% in relative humidity of greenhouse air (50.7±2.3%) compared to that of outdoor air (60.7±5.2%). In the same time period, the average values of total daily horizontal solar radiation, daily sunshine duration and wind speed were 467.8±67.8 cal cm^{-2}, 10.0±1.63 h and 0.82±0.26 m s^{-1}, respectively (Fig. 1).

Halved and pitted plums dried in 6 to 13 days based on the drying methods and the application of pretreatment (Fig. 2). The fastest drying occurred in

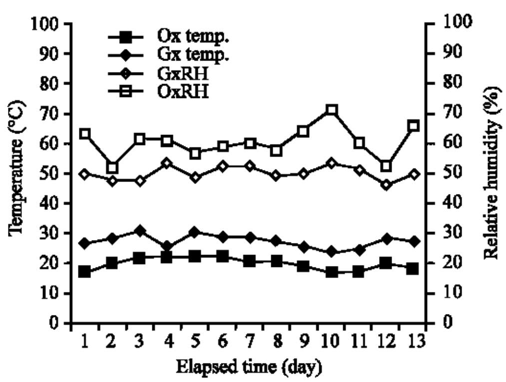

Fig. 1: Change of temperature and relative humidity of greenhouse and outdoor air during drying of Giant plum

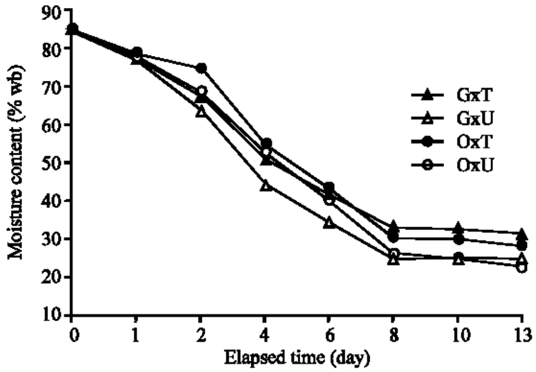

Fig. 2: Moisture change of halved and pitted Giant plum

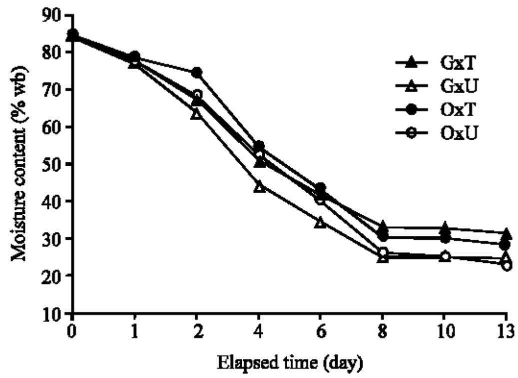

Fig. 5: Moisture change of halved and pitted Stanley plum

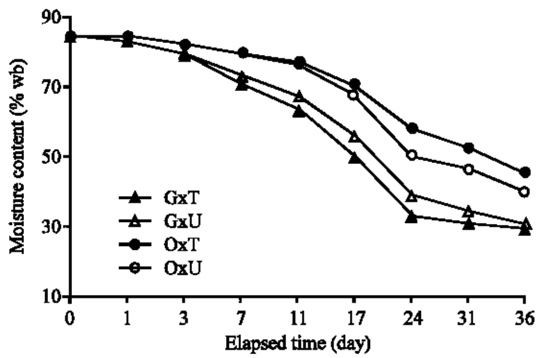

Fig. 3: Moisture change of whole Giant plum

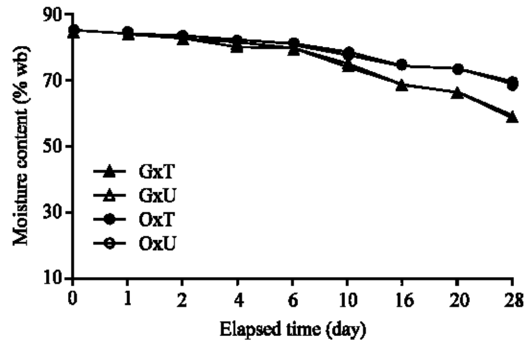

Fig. 6: Moisture change of whole Stanley plum

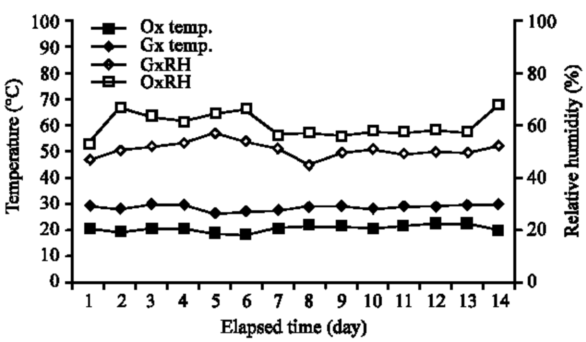

Fig. 4: Change of temperature and relative humidity of greenhouse and outdoor air during drying of Stanley plum

6 days with chemically pretreated samples (T) in the greenhouse dryer (G). The slowest drying occurred in 13 days with untreated samples (U) under open atmosphere, open sun drying, (O). The moisture of whole plums could not be lowered below 30% after 28 days and significant decaying was observed (Fig. 3).

Drying of stanley plum: During this drying process, daily average greenhouse air temperature was 28.4±1.1°C while daily average outdoor temperature was 20.4±1.2°C (Fig. 4). It means that greenhouse dryer provided 8°C hotter air on the average. In addition, this increase in air temperature resulted approximately in a reduction of 10% in relative humidity of greenhouse air (50.4±3.1%) compared to that of outdoor air (60.0±4.6%). In the same time period, the average values of total daily horizontal solar radiation, daily sunshine duration and wind speed were 409.0±48.5 cal cm^{-2}, 9.15±1.76 h and 0.76±0.3 m s^{-1}, respectively.

Halved and pitted plums dried in 7 to 13 days based on the drying methods and the application of pretreatment (Fig. 5). The fastest drying occurred in 7 days with untreated samples (U) in the greenhouse dryer (G). The slowest drying occurred in 13 days with untreated samples (U) under open atmosphere, open sun drying, (O). The moisture of whole plums could not be lowered below 30% after 28 days and significant decaying was observed (Fig. 6).

Drying of president plum: During this drying process, daily average greenhouse air temperature was 25.1±3.5°C while daily average outdoor temperature was 17.8±3.2°C (Fig. 7). It means that greenhouse dryer provided 7°C hotter air on the average. In addition, this increase in air

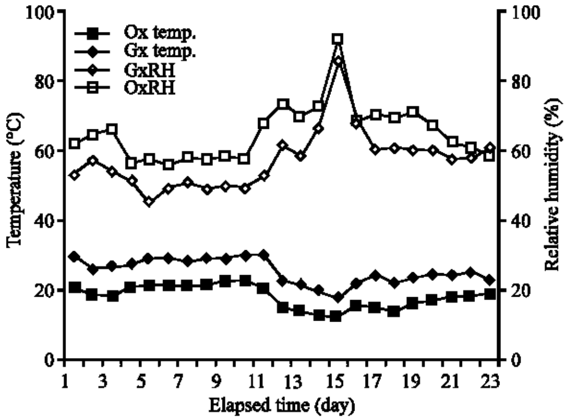

Fig. 7: Change of temperature and relative humidity of greenhouse and outdoor air during drying of President plum

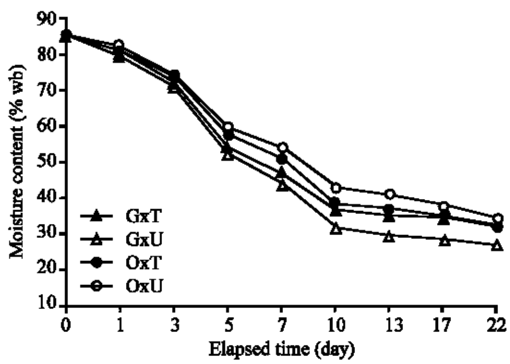

Fig. 8: Moisture change of halved and pitted President plum

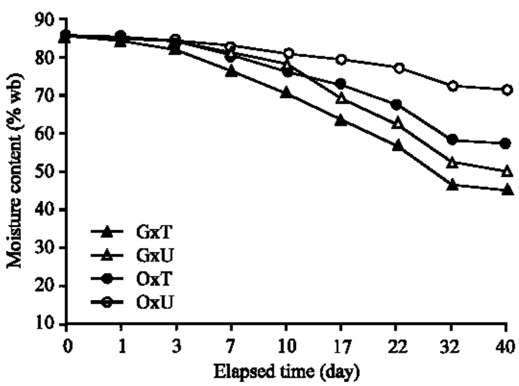

Fig. 9: Moisture change of whole President plum

temperature resulted approximately in a reduction of 8% in relative humidity of greenhouse air (57.0±8.6%) compared to that of outdoor air (64.7±8.6%). In the same time period, the average values of total daily horizontal solar radiation, daily sunshine duration and wind speed were 349.0±102.3 cal cm^{-2}, 7.27±3.48 h and 0.73±0.2 m s^{-1}, respectively. There are relatively higher variations in average weather values compared to the previous two drying trials for Giant and Stanley cultivars. These variation was caused by adverse weather conditions during the 11th to 19th days of drying trials

Table 2: Some chemical properties of halved/pitted prunes

	Stanley			Giant			President		
Treatments	WSSC	pH	TAC	WSSC	pH	TAC	WSSC	pH	TAC
GxT	66.0	4.33	0.40	64.0	3.77	0.69	68.2	3.8	0.50
GxU	65.0	4.36	0.38	66.4	3.80	0.67	69.8	3.8	0.87
OxT	65.8	4.44	0.23	66.9	3.92	0.64	68.5	3.9	0.67
OxU	67.3	4.55	0.31	66.0	3.98	0.64	67.6	3.8	0.54

Halved and pitted plums dried in 12 to 22 days based on the drying methods and the application of pretreatment (Fig. 8). The fastest drying occurred in 12 days with untreated samples (U) in the greenhouse dryer (G). The slowest drying occurred in 22 days with untreated samples (U) under open atmosphere, open sun drying, (O). The moisture of whole plums could not be lowered below 30% after 40 days and significant decaying was observed (Fig. 9).

Some chemical properties of dried plums (prunes): These chemical values belonged only to halved-pitted plums (H) since the whole plums decayed during drying trials (Table 2). All cultivars had relatively close WSSC values. Drying increased WSSC content of plums by 3.94, 4.43 and 5.07 times for Stanley, Giant and President cultivars, respectively. Chemical pretreatment and drying methods did not affect the WSSC values in an observable trend. pH values of fresh and dried plums were similar to each other. Stanley plum had relatively higher pH values (4.06-4.55) than other two cultivars. Chemical pretreatment and drying methods did not affect pH values in an observable trend, either. Total TAC decreased by 60.1, 29.0 and 28.3%, for Stanley, Giant and President, respectively as a result of drying. Once again, chemical pretreatment and drying methods did not affect the TAC values in an observable trend valid for all cultivars. However, solar dying and chemical pretreatment resulted in the highest TAC values for Stanley and Giant cultivars while solar drying and untreated plums resulted in the highest TAC for President.

DISCUSSION

Three plum cultivars had different sizes and harvest dates from each other. This indicates that the selection of plum cultivars can be critical for successful drying. Relatively smaller sizes of Stanley plum makes it more suitable for drying. However, relatively early harvest date of Giant plum gives more time and logically better drying conditions to dry it. The results revealed that the moisture content of whole plums could not be lowered to desirable moisture level of prune (25-30%) without microbial and nutritional spoilage under the weather condition like in Tokat, Turkey. Therefore, artificial hot air dryer can be an option to dry plums at drying temperatures higher than the temperatures obtained in greenhouse dryer. High investment and operation costs of these dryers limit their use for small productions in rural areas. Much more feasible alternative is to halve and pit the plums regardless of their cultivars. The combination of halving-pitting plums and greenhouse dying can be recommended as a suitable drying strategy to produce prune in the rural areas. Dipping plums in 1% NaOH solution for 15 sec did not have significant affect on the acceleration of the moisture loss except small increase in one case (halved plums of Giant plum and greenhouse drying). Therefore, some other chemical pretreatment such as alkali emulsion of ethyl oleate[6] can be tried and/or longer dipping time and hotter dipping solution temperature can be tried to accelerate the drying of plums.

Water Soluble Solid Content (WSSC) and total Tiratable Acid Content (TAC) of plums plays a significant roles in consumer acceptance[19-21]. WSSC is the indicator of sweet taste while TAC is the indicator of sour taste[22]. However, the establishment of a minimum index based on WSSC or WSSC/TAC needs to be evaluated for each cultivars[19]. For instance, Blackamber plums (*Prunes salicina* Lindell) should be harvested when they reach a minimum WSSC within the range of 10-12% and TAC is lower than 0.7%[19]. In other study, it is recommended that WSSC of plums should be equal to or above 18% at harvest time[21]. Based on these reports in the literature, WSSC values of prunes is very much above the recommended limit value of fresh plums while TAC values of prune is below the recommended limit value of fresh plums. Therefore, prune is expected to give sweeter taste than fresh plums. To determine the best quality attributes of prune appreciated by consumers, the sensory analysis including panelists to select the best prunes should be performed.

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